[0011] It is a further object of the present invention to provide a free-cutting copper alloy with excellent machinability and high impact resistance, which is suitable as basic material for the manufacture of products that need to be made of impact resistant material because they undergo a caulking process after a cutting process, such as tube connectors called "nipples," metal hinges for furnature, automobile sensor parts, and the like.

[0012] The objects of the present inventions are achieved by provision of the following copper alloys:

[0013] A free-cutting copper alloy with an excellent easy-to-cut feature which is composed of 69 to 79 percent, by weight, of copper, 2.0 to 4.0 percent, by weight, of silicon, 0.02 to 0.4 percent, by weight, of lead and the remaining percent, by weight, of zinc, wherein the percent by weight of copper and silicon in the copper alloy satisfy the relationship $60 \leq X - 3Y \leq 70$, wherein X is the percent, by weight, of copper, and Y is the percent, by weight, of silicon; and the copper alloy has a metal construction comprising multiple phases integrated to form a composite phase, wherein the composite phase is an α phase matrix having a total phase area comprising not more than 5% of a β phase, and 5-70% of the total phase area is provided by at least one phase selected from the group consisting of a γ phase, a κ phase, and a μ phase.. For purpose of simplicity, this copper alloy will be hereinafter called the "first invention alloy."

[0014] Lead does not form a solid solution in the matrix but instead disperses in granular form to improve machinability. Silicon improves the easy-to-cut property by producing a gamma phase (in some cases, a kappa phase) in the structure of metal. Silicon and lead are the same in that they are effective in improving machinability, though they are quite

different in their contribution to other properties of the alloy. On the basis of that recognition, silicon is added to the first invention alloy so as to bring about a high level of machinability meeting industrial requirements while making it possible to greatly reduce the lead content. That is, the first invention alloy is improved in machinability through formation of a gamma phase with the addition of silicon.

[0015] The addition of less than 2.0 percent by weight of silicon cannot form a gamma phase sufficient enough to secure industrially satisfactory machinability. With an increase in the addition of silicon, machinability improves. But with the addition of more than 4.0 percent by weight of silicon, machinability will not go up in proportion. The problem is, however, that silicon is high in melting point and low in specific gravity and also liable to oxidize. If unmixed silicon is fed into the furnace in the melting step, silicon will float on the molten metal and is oxidized into oxides of silicon (silicon oxide), hampering the production of a silicon-containing copper alloy. In producing the ingot of silicon-containing copper alloy, therefore, silicon is usually added in the form of a Cu-Si alloy, which boosts the production cost. Due also to the cost of making the alloy, it is not desirable to add silicon in a quantity exceeding the saturation point or plateau of machinability improvement, that is, 4.0 percent by weight. An experiment showed that when silicon is added in the amount of 2.0 to 4.0 percent by weight, it is desirable to hold the content of copper at 69 to 79 percent by weight in consideration of its relation to the content of zinc in order to maintain the intrinsic properties of the Cu-Zn alloy. For this reason, the first invention alloy is composed of 69 to 79 percent by weight of copper and 2.0 to 4.0 percent by weight of silicon, respectively. The addition of silicon improves not only the machinability but also the flow of the molten metal in casting, strength, wear resistance, resistance to stress corrosion cracking, and high-temperature oxidation resistance. However, these characteristics are not

seen unless the percent by weight of copper and silicon in the first invention alloy satisfies the relationship $60 \leq X - 3Y \leq 70$, wherein X is the percent, by weight, of copper and Y is the percent, by weight of silicon. Also, the ductility and de-zinc-ing corrosion resistance will be improved to some extent.

[0016] The addition of lead is set at 0.02 to 0.4 percent by weight for this reason. In the first invention alloy, a sufficient level of machinability is obtained by adding silicon that has the aforesaid effect even if the addition of lead is reduced. Yet, lead has to be added in an amount not smaller than 0.02 percent by weight if the alloy is to be superior to the conventional free-cutting copper alloy in machinability, while the addition of lead in an amount exceeding 0.4 percent by weight would have adverse effect, resulting in a rough surface condition, poor hot workability such as poor forging behavior, and low cold ductility. Meanwhile, it is expected that such a small content of not higher than 0.4 percent by weight will be able to clear the lead-related regulations however strictly they are to be stipulated in the advanced nations including Japan in the future. For that reason, the addition range of lead is set at 0.02 to 0.4 percent by weight in the first and also second to eleventh invention alloys which will be described later.

[0017] Another embodiment of the present invention is a free-cutting copper alloy also with an excellent easy-to-cut feature which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; one additional element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc, wherein the percent by weight of copper and silicon in the copper alloy satisfy the relationship $60 \leq X - 3Y \leq 70$, wherein X is the percent, by weight, of